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# Note on Nocturnal Radiation Reversal

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**ABSTRACT**—Nocturnal radiation reversal is essentially an unsteady, advective effect. It requires that clouds or fog drift over a previously cooled surface. In the case of higher clouds, reversal can occur only with a sufficiently intense surface temperature inversion.

Statistics of authentic cases of reversal occurring at Aspendale, Australia (38°02′S, 138°06′E), are given and related to other meteorological variables.

## 1. GENERAL CONSIDERATIONS

Land surface temperatures are controlled by radiative and other heat exchange processes. By night, if the surface radiates as a blackbody,

$$R_N=\sigma(T_{ac}^4-T_s^4)=\mathcal{L}E+H+G \tag{1}$$

where $R_N$ is net (or effective) radiation, $\sigma$ is Stefan's constant, $T_{ac}$ is an appropriately defined sky (air plus cloud) temperature, $T_s$ is the surface temperature, $\mathcal{L}$ is the latent heat of condensation, $E$ and $H$ are fluxes of water vapor and sensible heat from ground to air, and $G$ is the flux of heat into the ground.

From Paltridge's (1970) "opaque and clear" model for atmospheric radiation (also Swinbank 1964), downward radiation, $\sigma T_{ac}^4$, is given by

$$\sigma T_{ac}^4=\epsilon\sigma T_a^4+C(1-\epsilon)\sigma T_c^4 \tag{2}$$

where $\epsilon$ is a slowly varying function of temperature having a value, according to Paltridge, of about 0.7 at normal temperature; $T_a$ is air temperature. [According to Geiger (1965, p. 20), for a mixing ratio of about 5 g/kg, 72 percent of $\epsilon\sigma T_a{}^4$ is contributed by the lowest 87 m, 6.4 percent by the next 89 m, and so on, so that $T_a$ must be regarded as a weighted mean temperature of the lowest few hundred meters.] $T_c$ is cloud-base temperature, and $C$ is the proportion of sky covered by clouds.

For a clear sky, $(C=0)$; $T_{ac}=\epsilon^{1/4}T_a\approx 0.91T_a$; and, for $R_N$ to be positive (the case of nocturnal radiation reversal), $T_s<\epsilon^{1/4}\ T_a$, which would require a low-level temperature inversion in excess of 20°C. This situation is encountered rarely, if at all.

With an overcast sky $(C=1)$ and very low clouds, or sufficiently thick fog, $T_c\approx T_a\approx T_{ac}$, and any inversion would result in positive $R_N$. Such an inversion would tend to disappear as the result of heat exchanges, but consideration of heat capacities and fluxes suggests that, once formed, it could persist for some hours if the subsoil were cold. Thus, radiation reversal could arise if cloud or fog were advected over ground previously cooled below cloud temperature.

For $C=1$ and higher cloud, $T_a>T_c$, normally $T_a\approx T_c+6z_c$ where $z_c$ is the cloud base height in kilometers. Thus, from eq (2), $T_{ac}<T_a$, and for positive $R_N$, an inversion in excess of a certain value is required; that is,

$$T_a^4-T_s^4>(1-\epsilon)(T_a^4-T_c^4) \tag{3}$$

or, more roughly,

$$T_a-T_s>(1-\epsilon)(T_a-T_c). \tag{4}$$

In terms of eq (1), radiation reversal requires that $\mathcal{L}E+G$ must outweigh negative $H$, and this would be favored by dry air moving over moist, cold ground.

A complete prediction of the course of events in time would require:

1. Solution of the equations of eddy transfer of heat and water vapor in the air up to the top of the boundary layer.
2. Solution of the equations of heat and water substance diffusion in the soil, covering levels participating in change.
3. Assessment of advective and other changes of temperature and water vapor in the air and, for the solution of (1), changes of wind due to advection and changes of pressure gradient must be added.
4. Prediction of cloud and its radiative temperature.

In regard to (1) and (2), the prediction may be regarded as a boundary-layer problem.

It is known that under exceptional circumstances net long wave radiation can be positive (Geiger 1965, p. 18), but, except in Antarctica, little attention appears to have been paid to the phenomenon.

Loewe (1967), Rusin (1964, p. 289), Weller (1967), and MacDowall and Tribble (1962, p. 148) have references to positive net radiation over Antarctica with the sun below the horizon. Weller indicates that at Mawson (67°36′S, 62°31′E), about 4 percent of observations of $R_N$ with the sun below the horizon show positive $R_N$. The tables of MacDowall and Tribble give evidence of a much larger incidence of positive $R_N$ during some parts of the polar night at Halley Bay (75°60′S, 26°39′W).

## 2. SOME STATISTICS FOR ASPENDALE

Statistics relating to nocturnal radiation reversal during 4 yr of radiation records obtained at Aspendale, Victoria, Australia (38°02′S, 145°06′E), are set forth in this section. Net radiation, measured with a Funk radiometer [1] over grass, is integrated over each hour.

The records have been carefully checked for consistency, and only those occasions where measured $R_N$ exceeded 0.5 $mW \cdot cm^{-2}$ have been included in the summary. Thus, all cases listed below can be regarded as genuine reversals.

During these 4 yr, 61 hr ($\approx$0.4 percent) on 23 nights ($\approx$2 percent) are found to have radiation reversal. If smaller and less certain reversals are included, the figures may be as high as 2 percent of hours occurring on 6 percent of nights. Values of $R_N$ ranged up to 1.6 $mW \cdot cm^{-2}$, and for the 61 hr they averaged 0.7 $mW \cdot cm^{-2}$. These values may be contrasted with the annual nocturnal mean of $-4.0$ $mW \cdot cm^{-2}$, varying little from month to month.

[1] Mention of a commercial product does not constitute an endorsement.

Table 1 is a frequency analysis of hours of reversal on nights with at least one such hour. Also listed is frequency of duration of reversal.

Frequency of radiation reversal according to time of night is set forth in table 2. For this purpose, the night has been divided into quarters, the length of which varies with time of year. Frequency of radiation reversal according to month is given in table 3.

For the purpose of assessing weather conditions accompanying reversal, local Aspendale (or Melbourne, Australia, Airport in the case of cloud observations) data were used, as well as plotted synoptic charts. The Aspendale station is within 200 m of Port Phillip Bay, Australia, and the airport is 37 km away on a bearing of 332°, some 15 km inland. Thus, cloud and fog details, available at the airport at half-hourly intervals, are not always representative for Aspendale. Table 4 shows the frequency of hours of reversal at Aspendale with cloud amount and height at the airport.

Table 5 lists frequency of reversal in various categories of wind direction and speed for both surface and geostrophic winds. Surface wind was read from the record of a Dines anemograph, with sensing head at 12 m.

Finally, table 6 shows the frequency of reversal with precedent rain and with rain at time of observation.

TABLE 1.—*Frequency of hours of reversal, and duration*

| | Hours of reversal | | | | | | | | Total |
|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | |
| Frequency (nights) | 8 | 4 | 5 | 4 | – | 1 | – | 1 | 23 nights |
| Duration (No. of occurrences) | 13 | 8 | 4 | 3 | – | – | – | 1 | 29 (61 hr) |

TABLE 2.—*Frequency of radiation reversal during the 4 quarters of the night*

| | Quarter | | | | Total |
|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | |
| Frequency (hr) | 0 | 9 | 25 | 27 | 61 |

TABLE 3.—*Frequency of nights with at least 1 hr of reversal*

| | Month | | | | | | | | | | | | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | J | F | M | A | M | J | J | A | S | O | N | D | |
| Frequency (nights) | 1 | 4 | 0 | 5 | 2 | 8 | 0 | 1 | 0 | 2 | 0 | 0 | 23 |

## 3. REMARKS ON THE TABLES

Radiation reversal can extend over a large portion of a night but rarely exceeds 4 hr. It occurs in the latter hours of the night after low soil temperatures have been established and predominantly in autumn and early winter, the season of fogs. Advective fog is well known to occur most frequently with light east wind, but can occur with light wind from any quarter.

Recent rain at Aspendale is not a necessary condition for reversal, and concomitant rain occurs in only a small proportion of cases.

On at least two occasions, reversal has occurred with middle-level clouds only, and both of these were occasions of strong north geostrophic wind.

TABLE 4.—*Frequency of hours of reversal with clouds as specified*

| | Cloud amount (octants) | | | | Height of cloud base* (m) | | | |
|---|---|---|---|---|---|---|---|---|
| | 0–2 | 3–5 | 6–8 | Total | 0–300 | 300–2400 | >2400 | Total |
| Hours of reversal | 11 | 8 | 42 | 61 | 37 | 16 | 6 | 59† |

*Lowest cloud base when more than one height is reported.
†For 2 hr, no cloud was reported at the airport, but there was evidence of fog at Aspendale.

TABLE 5.—*Reversal frequency with wind direction and speed*

| Surface wind* (m/s) | N | E | S | W | Total |
|---|---|---|---|---|---|
| | Wind direction | | | | |
| | Hours | | | | |
| 0–1 | 24 | 10 | 1 | 4 | 39 |
| 1–3 | 4 | 1 | 2 | 1 | 8 |
| 3–5 | 3 | 0 | 2 | 4 | 9 |
| >5 | 2 | 3 | 0 | 0 | 5 |
| | | | | | 61 hr |
| Geostrophic wind (m/s) | Nights | | | | |
| 1–6 | 0 | 9 | 2 | 2 | 13 |
| 5–10 | 0 | 2 | 0 | 1 | 3 |
| 10–15 | 0 | 2 | 1 | 0 | 3 |
| >15 | 2 | 0 | 0 | 0 | 2 |
| | | | | | 21 nights† |

*Direction of vane, not necessarily of wind
†On two nights the geostrophic wind was virtually zero.

TABLE 6.—*Frequency of reversal with rain at Aspendale*

| | Rain during reversal | Rain during previous 48 hr | Neither | Total |
|---|---|---|---|---|
| Frequency (nights) | 2 | 9 | 12 | 23 |
| Frequency (hr) | 5 | 20 | 36 | 61 |

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## REFERENCES

Geiger, Rudolf, *The Climate Near the Ground,* Harvard University Press, Cambridge, Mass., **1965**, 611 pp.

Loewe, Fritz, "Antarctic Meteorology," *Encylcopaedia of Atmospheric Sciences and Astrogeology,* Vol. 2, Reinhold Publishing Corp., New York, N.Y., **1967**, pp. 19–26.

MacDowall, J., and Tribble, D. T., "Radiation Observations," *Royal Society International Geophysical Year Antarctic Expeditions of Halley Bay, 1955–59,* Vol. 3, Royal Society of London, England, **1962**, pp. 111–122.

Paltridge, Garth W., "Day-time Long-wave Radiation From the Sky," *Quarterly Journal of the Royal Meteorological Society,* Vol. 96, No. 410, London, England, Oct. **1970**, pp. 645–653.

Rusin, Nikolaĭ Petrovich, *Meteorological and Radiational Regime of Antarctica,* Israel Program for Scientific Translations, Jerusalem, **1964**, 355 pp. (translation of *Meteorologicheskiĭ i radiatsionnyĭ rezhim Antarktidy,* Gidrometeoizdat, Leningrad, U.S.S.R., 1961, 496 pp.).

Swinbank, William C., "Longwave Radiation From Clear Skies," (Discussion), *Quarterly Journal of the Royal Meteorological Society,* Vol. 90, No. 386, London, England, Oct. **1964**, pp. 488–493.

Weller, Gunter E., "Radiation Fluxes Over an Antarctic Ice Surface, Mawson, 1961–62," *ANARE Publication* No. 96, Australian National Antarctic Research Expeditions, Melbourne, **1967**, 106 pp.

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